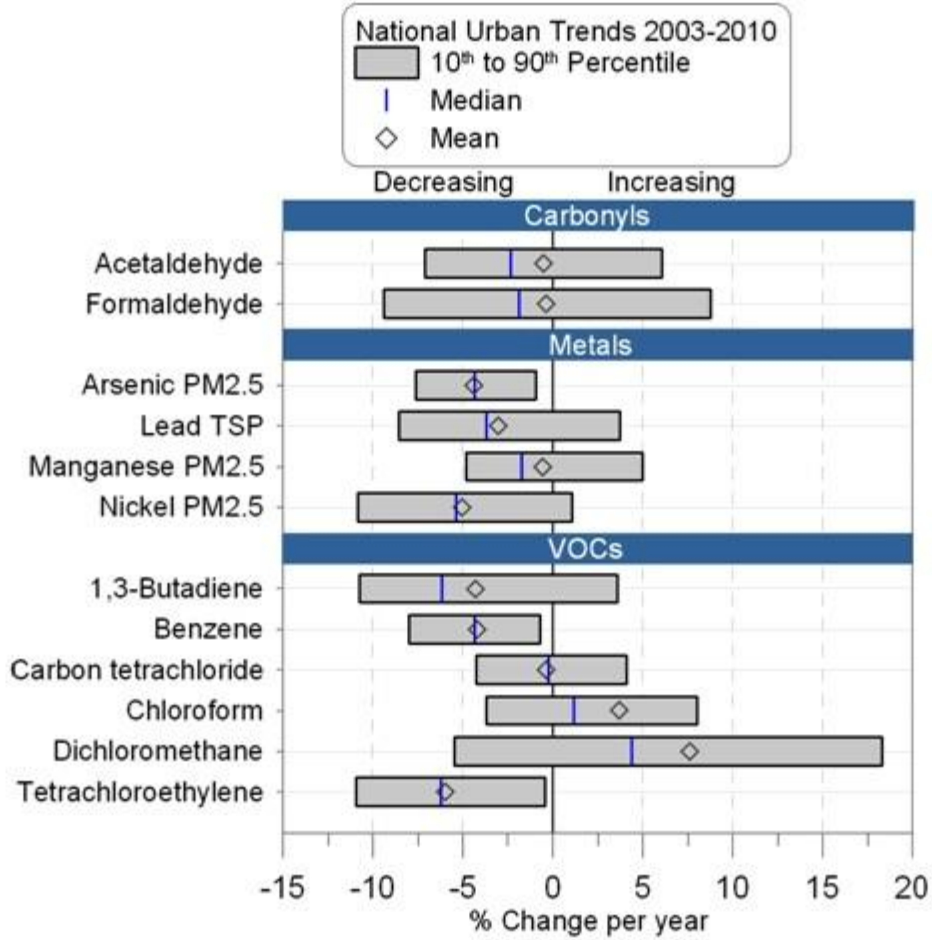
Quantifying and Interpreting Trends



Sonoma Technology, Inc.

Trends Overview
Motivation

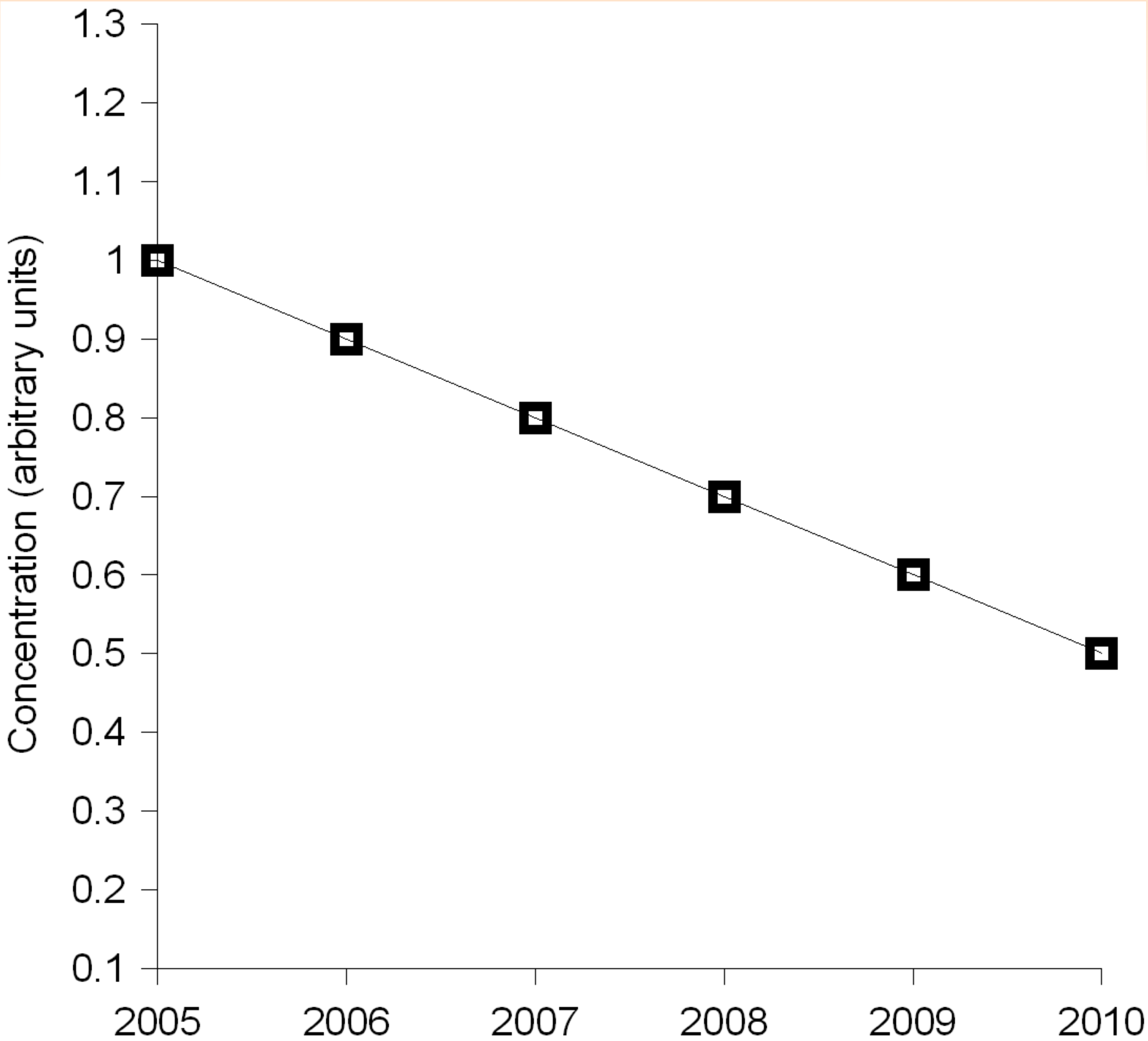
Assessing trends is useful – and necessary from a policy perspective.

- Are air toxics concentrations changing?
- Are the ambient concentration changes in response to changes in emissions?

Suggested Analyses

Questions	Examples of Analyses
Do air toxics concentrations change over time?	
What are the annual trends in air toxics concentrations?	• Plot annual average concentrations and MDLs of key species to evaluate trends • Perform linear regressions • Compare begin- and end-year concentrations • Compare multi-year averages across begin and end years
How might changes in air toxics concentrations be related to emissions controls?	• Compare trends in co-emitted pollutants • Assess timing of controls and expected reductions relevant to local monitoring of pollutants

Trends – Comparative Example

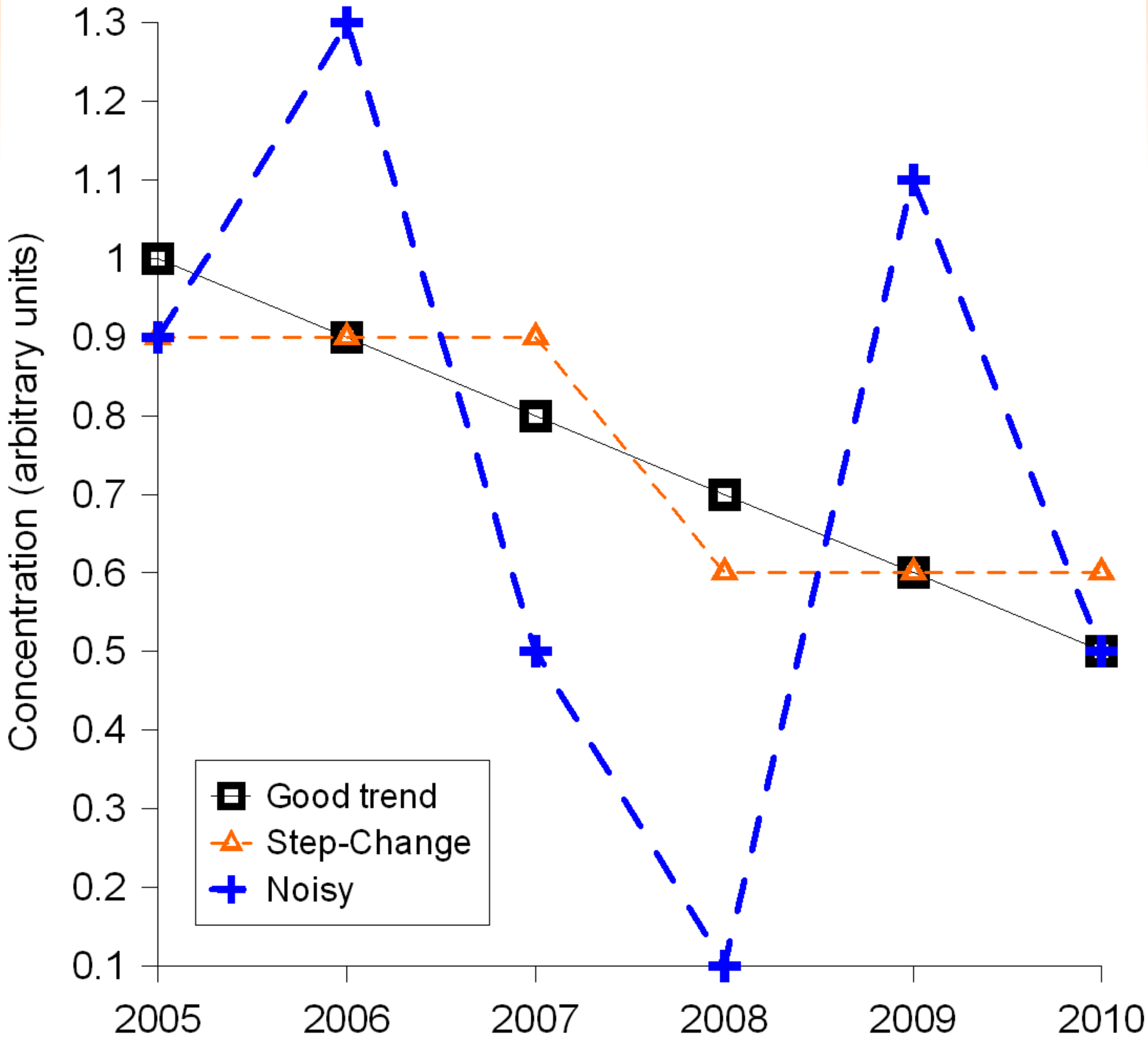


- Platonic ideal of a trend
- Constant change
- No noise

Trends – Comparative Example

- Step-change trend
- Flat trend with a single drop in concentration
- Not going to fit well to a linear regression
- Clear difference between start and end periods

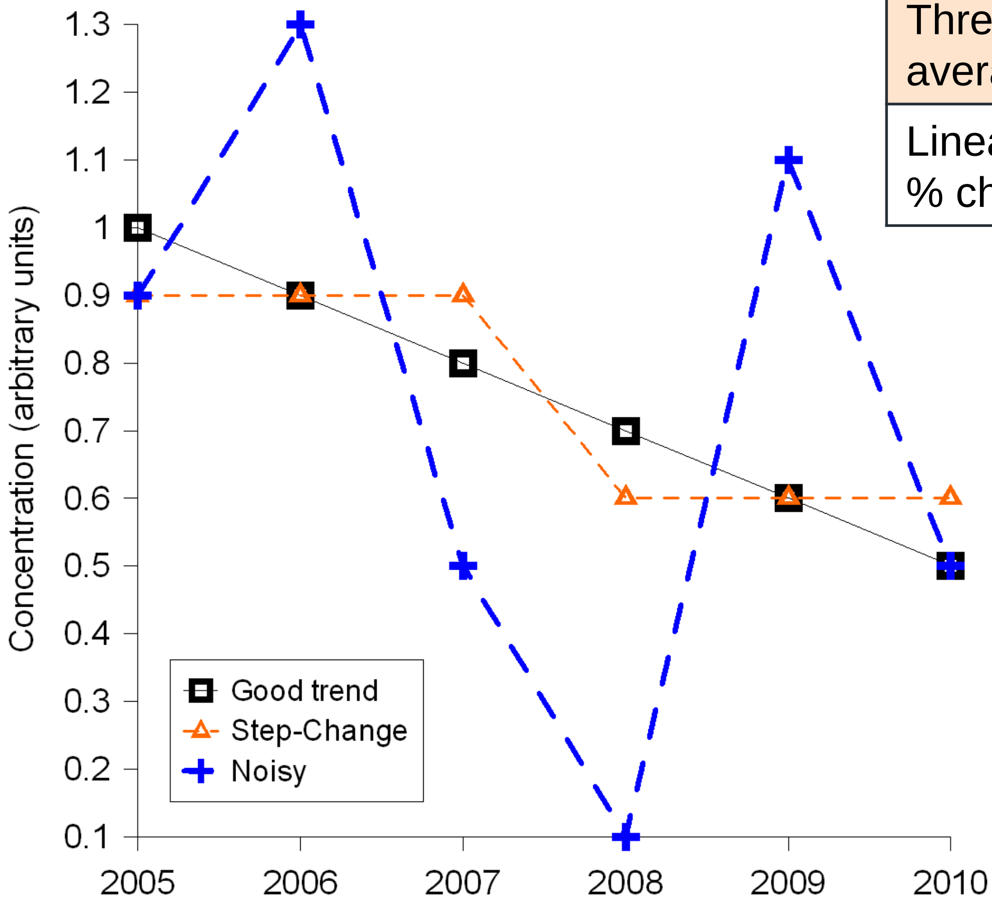
Trends – Comparative Example



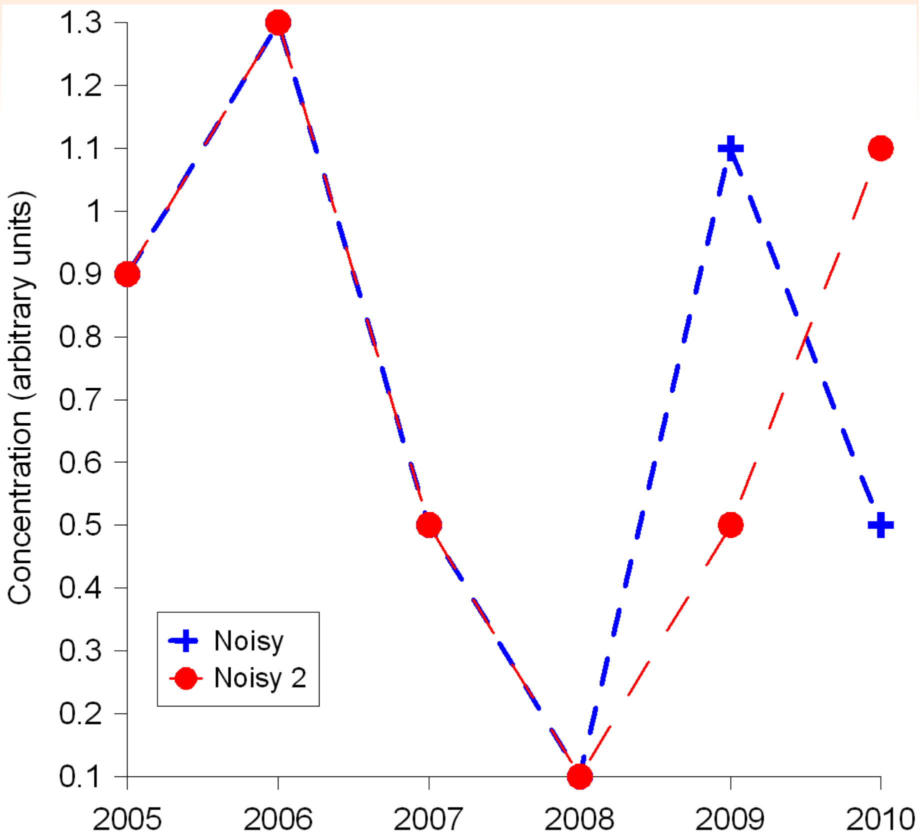
- Noisy time series
- Poor fit for linear regression
- Is the trend real? Will the next year go back up to 1.5?

Trends – Comparative Example

Trend Analysis	Good Trend	Step-Change	Noisy Trend
Begin- and end-year % change	50	33	44
Three-year average % change	33	33	37
Linear regression % change	50	39	43



Trends – Comparative Example



Trend Analysis	Noisy Trend	Noisy Trend 2
Begin- and end-year % change	44	-22
Three-year average % change	37	37
Linear regression % change	43	26

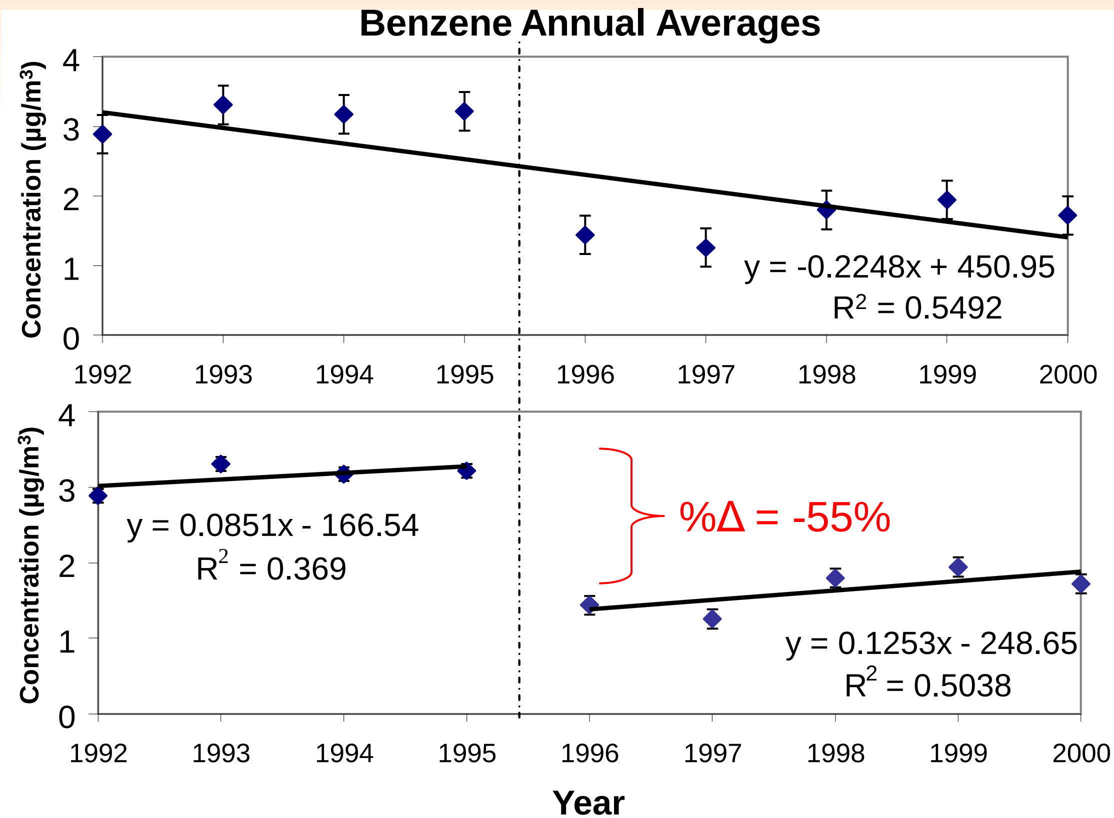
Changing just one year can make a big difference in analysis results!

Trends Tips

- Visually inspect trends.
- Understand data uncertainties.
- Obtain consensus (or weight of evidence) among results from different approaches to increase our certainty in the observed trends.
- Trends analyses can be complicated by data below MDL, changing methods, and step-changes in ambient concentrations.

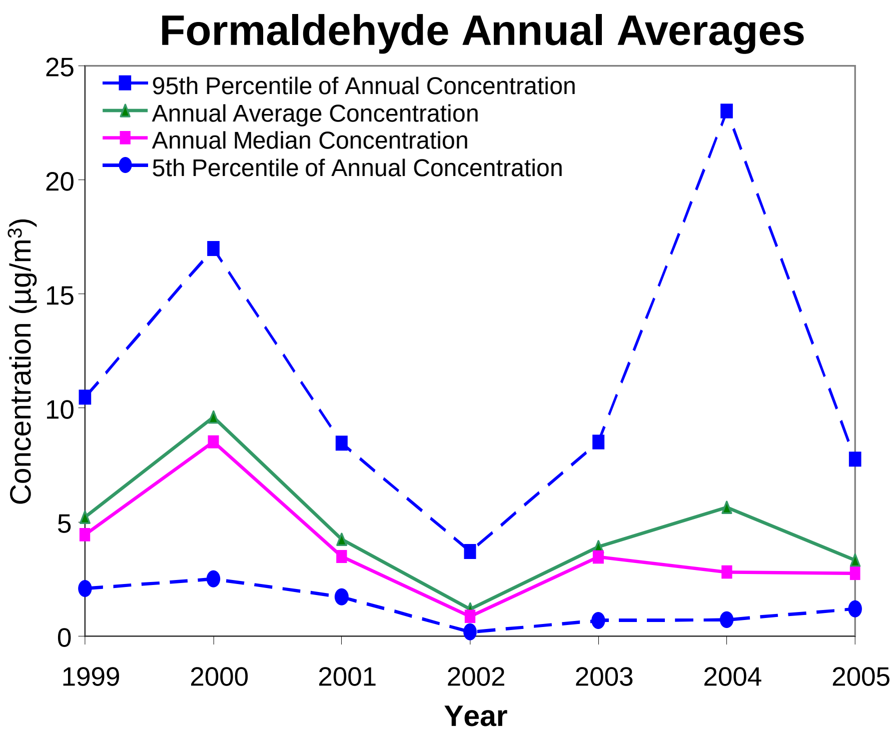
Visualizing Trends
Line Graphs

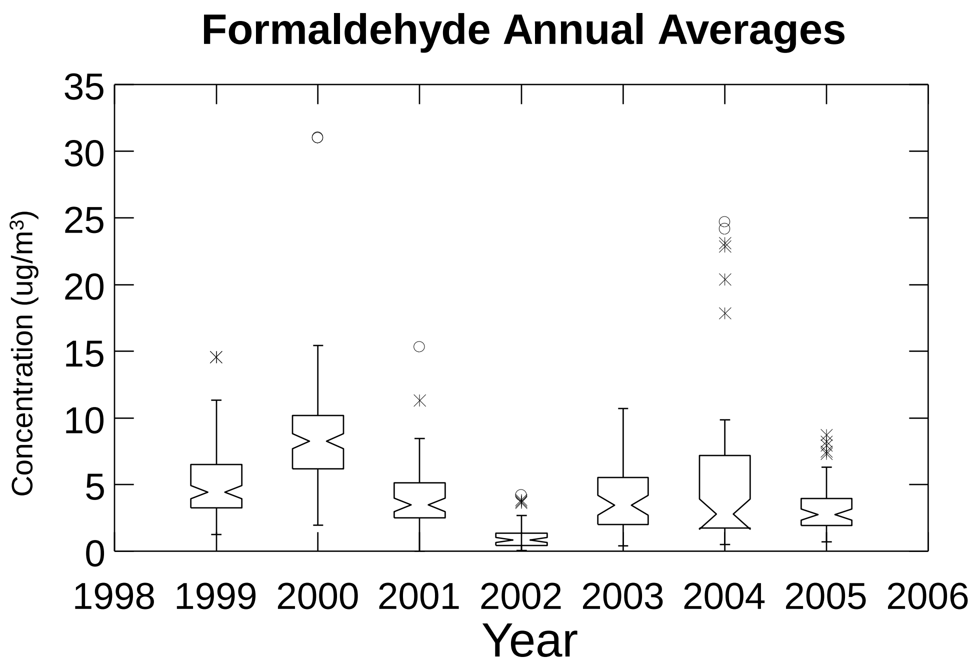
- May need to break a long-term trend into shorter time intervals because of significant changes in emissions.
- E.g., benzene in gasoline was significantly reduced in several urban areas starting in the mid-1990s when reformulated gas (RFG) was introduced. Dramatic reductions were observed in ambient benzene concentrations.
- Both plots contain the same data. If one trend line is used, the overall trend decreases. If two trend lines are segregated by the RFG year (1995), the benzene concentrations are relatively flat before and after RFG implementation.
- In this case, the difference between the two time periods may be a better quantitative reflection of how benzene concentrations changed.



The figure shows the same benzene annual averages fitted with regression lines in two ways. The first fits all data with one regression line and the second takes into account a large step change that occurred from regulations put into effect in 1995.

Visualizing Trends



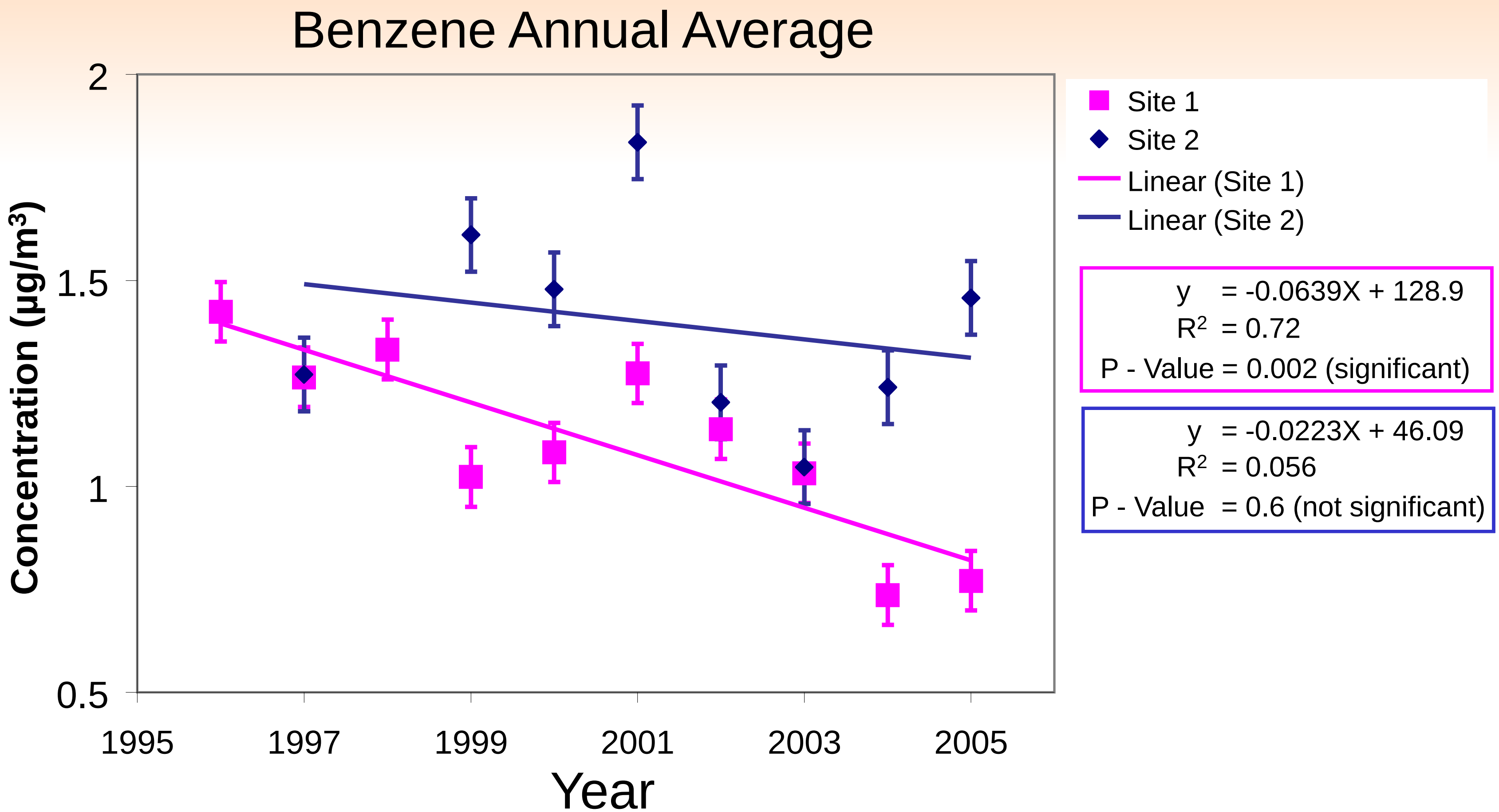


Quantifying Trends
Approach

- Initial investigation of trends
  - Inspect first and last year of the trend period or two multi-year averages for change.
  - Use simple linear regression to determine the magnitude of a trend over the trend period.
- Quantifying trends
  - The percent difference between the first and last year of the trend period provides a rough sense of the change.
  - The difference between two multi-year averages provides another measure of change and helps smooth out possible influences of meteorology.
  - The percent change per year is provided by the slope of the regression line. This “normalized” value allows the analyst to compare changes across varying lengths of time (i.e., sites with different trend periods).

Quantifying Trends

Approach



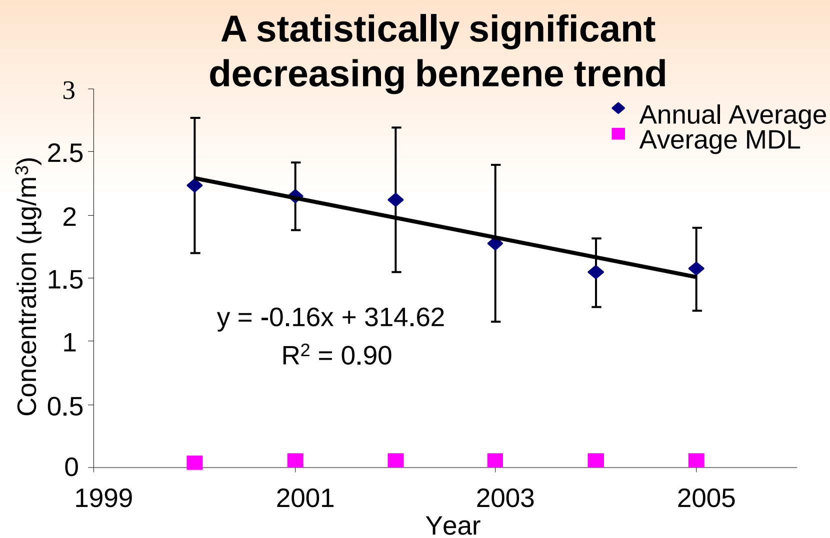
Testing the significance of the observed trends:

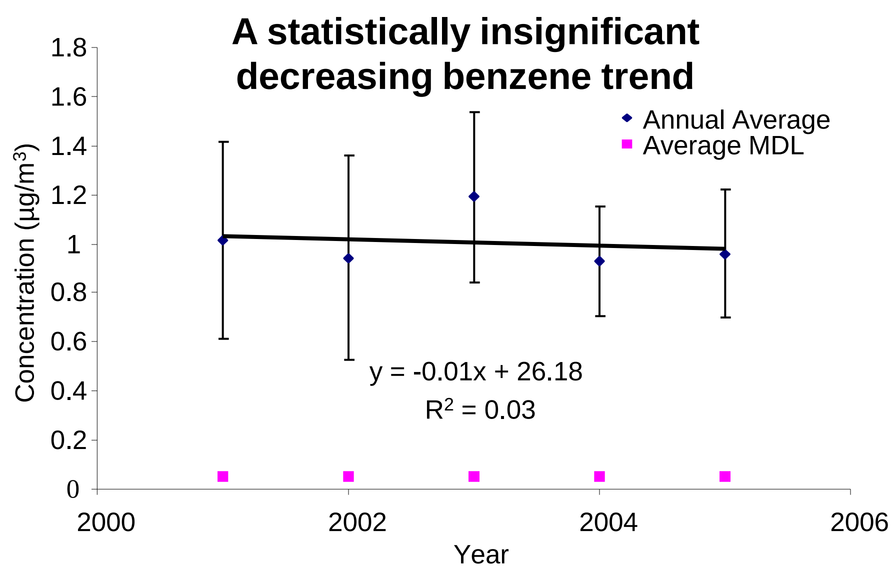
- Calculate the significance of the slope using the F-test. The F-test provides a statistical measure of the confidence that there is a relationship between the two variables (i.e., the regression line does not have a slope of zero, which would indicate that the dependent variable is not related to the independent variable).

Statistically Significant Trends

Comparing trends:

- Site-level trends for benzene from two U.S. sites.
- Confidence in these results is high. The data are mostly above detection, MDLs are consistent for the whole trend period, and no outliers appear to influence the trend.





Quantifying Trends

Interpreting Linear Regression Output

- Example of output from a linear regression of annual average benzene concentrations:

Metric	Value
Slope	-0.0078
Intercept	15.8
R^2	0.78
Percentage change	-49.7
Percentage change per year	-6.2
F-Statistic	20.9
P-value	0.0038
Confidence level	99.6

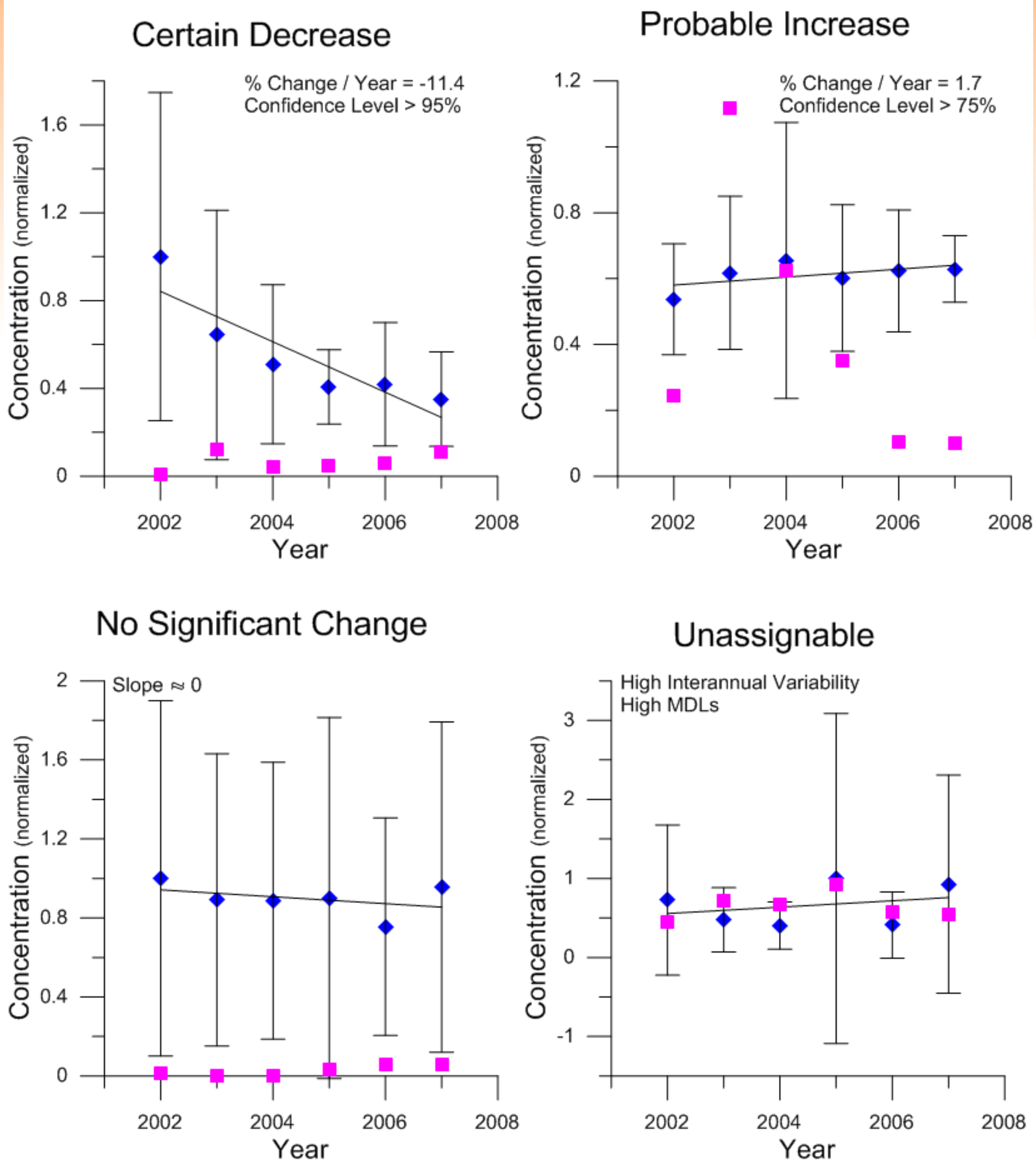
This output example shows a decline in annual average benzene concentrations over time with > 95% confidence and slope not equal to zero.

- The output is interpreted as follows:
  - **Slope, intercept, R^2, percentage change, percentage change per year.** Indicate the slope of the line, y-axis intercept, fraction of variation accounted for, percentage change between first and last year of the line, and percentage change divided by number of years.
  - **F-statistic or F-ratio.** F-ratio is used to test the hypothesis that the slope is 0. The F-ratio is large when the independent variable(s) helps to explain the variation in the dependent variable. Therefore, large F-ratios indicate a stronger correlation between the two variables (i.e., the slope of the regression line is NOT zero).
  - **P-value.** The P-value is the probability of exceeding the F-ratio when the group means are equal (generally, 95% confidence is used as a cutoff value, corresponding to a P-value of 0.05).

Trend Categories

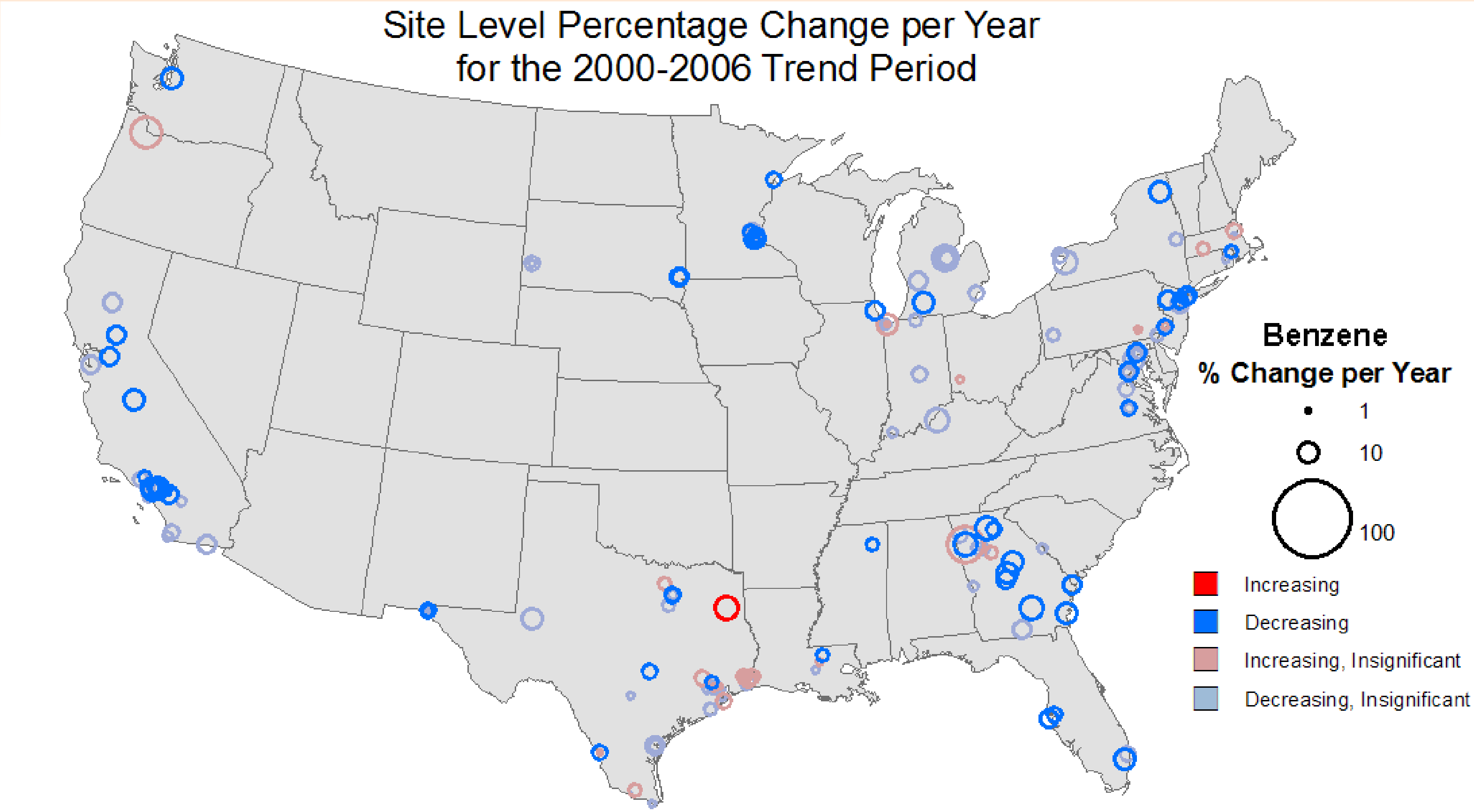
Conceptual illustration of some trend categories:

- certain decrease
- probable increase
- no significant change
- unassignable



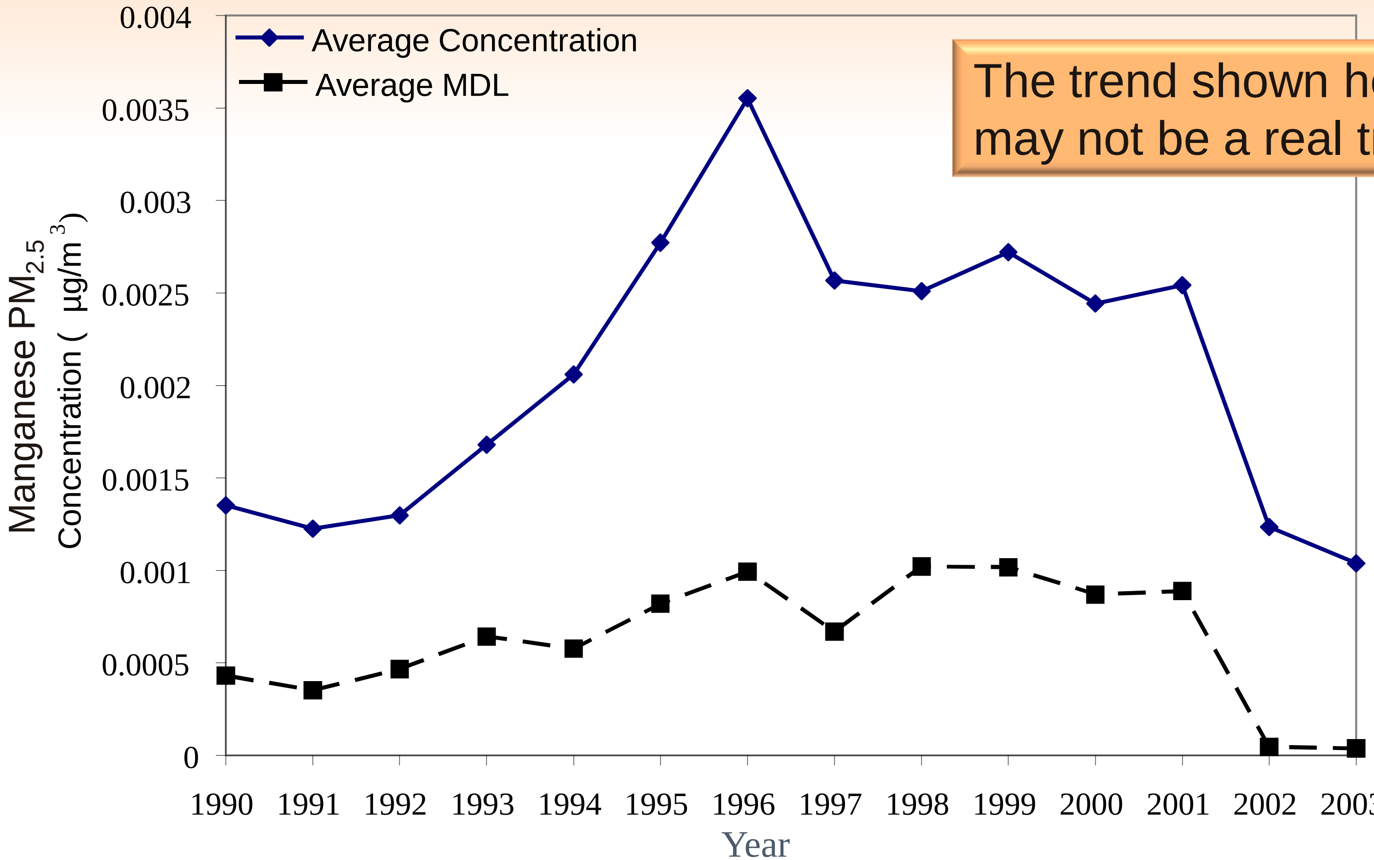
The data have been normalized to simplify the plots. Blue diamonds are annual mean concentrations, pink squares are annual mean MDL concentrations, and error bars indicate standard deviation in the annual mean concentration.

Summarizing Trends
Example – Spatial Distribution



This map shows the benzene site-level percentage change per year for 2000–2006. Many sites in the United States show a statistically significant decline in benzene concentrations over the period. The sites exhibiting increases over that time typically do not show statistically significant trends. These data suggest relatively high confidence that national benzene concentrations are declining nationally compared to the 2000 level. Statistical significance was quantified using the F-test at the 95% confidence level.

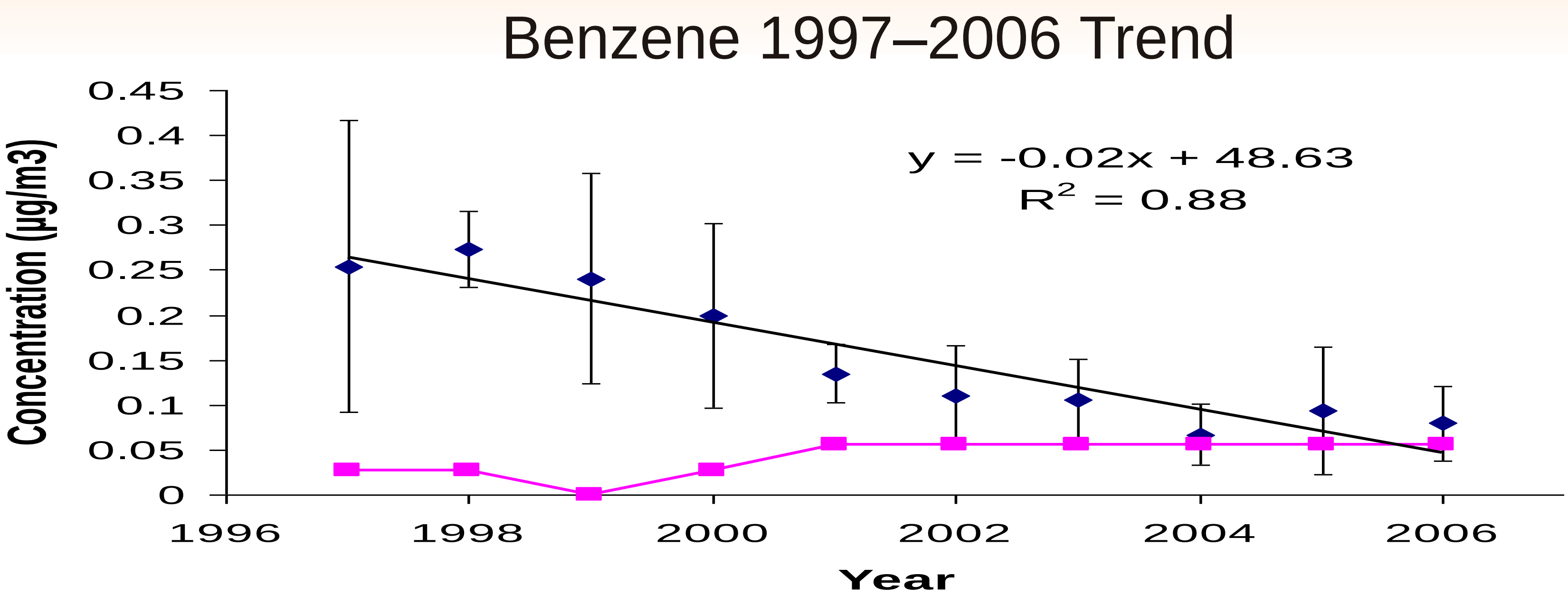
MDLs and Trends Assessment



The trend shown here may not be a real trend.

In the national-level investigation of Mn trends, MDL trends were similar to concentration trends, making the reliability of the overall ambient trend questionable. This example shows average Mn $PM_{2.5}$ concentrations and MDLs from 1990 to 2003. For this data set, Hyslop and White (2007) showed that reported MDLs are much lower than actual detection limits. Current recommendations are to be cautious with data within a factor of 6 to 10 of the reported MDL.

MDLs and Trends Assessment

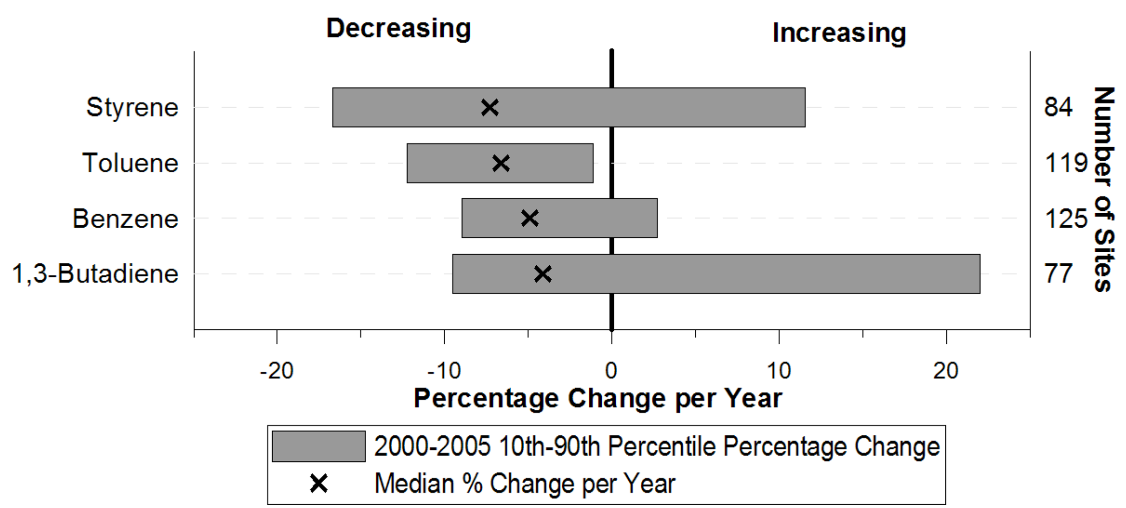


In contrast to the previous Mn $PM_{2.5}$ trend, this benzene trend does not show influence from a change in MDL (i.e., the trends in concentration and MDL show different patterns).

Summarizing Trends

Example – Percentage Change Per Year

- The bar chart summarizes trends in % change per year for selected mobile source air toxics for 2000–2005 data. The 10th, 50th, and 90th percentile of site-specific percentage change per year are plotted. The number of sites included in percentile calculations is also provided.
- A range of results is seen across the network (i.e., 10th to 90th percentile sites); however, most sites are experiencing declines of a few % per year with remarkable consistency (see median).
- 1,3-butadiene and styrene show a wider range of % changes by site.
- Benzene and toluene show similar ranges in % change per year and less variability in trends across the United States than 1,3-butadiene and styrene.
- Toluene is decreasing at 90% of sites by about 2% to 12% per year, while benzene is decreasing at most sites and may be increasing at some sites.



More Trends Analysis Questions

- Are concentration levels changing at a monitoring site?
- Are changes consistent across sites, areas, or regions?
- Are changes consistent across pollutants or pollutant groups?
- Are changes consistent across time periods?
- Are changes consistent with expectations (e.g., emissions controls, changes in population)?